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Development of an Automatic Label Attaching System Using a Robot Vision in Variable Situation

*이 용중
*창원기능대학 전기과

Abstract :
A cold & hot rolling coil production line of iron mill consists of a kind of coherent automatic process, but an automatic labelling process still had technical difficulties in the automation of its process. The reason for difficulties in building an automatic process is that quantitative data for each rolled coil from every shipping is not easy to receive from the previous process. It is not possible to apply for a general and simple purpose robot that is actually worked through a taught position to the process because the size and direction of the coil has differed on every shipping.

From these reasons, we introduce a robot vision system to accept an expected variable situation and to ensure the stability and flexibility of the process.

This paper examines a study applied for similar cases and finds the position and direction of rolled coil using the moment invariant algorithm proposed by Hu. In addition, the camera calibration and position error compensation algorithm is applied by the analysis of the relationship of transition in a space coordinate system.

The construction of a robot vision system proposed by this paper is a more intellectual system than that of the automatic labelling system, which is already used to the Daihen steel mill of NEW JAPAN steel mill co.ltd in Japan, and shows a better independent operation in the field of production.

Keywords : position error compensation algorithm, camera calibration, robot vision system, image processing, moments invariant,

1. Introduction

Most of a cold & hot rolling coil production line of iron mill consists of a kind of coherent automatic process, but an automatic labelling as a final process still had technical difficulties in the automation of its process. A finished product of rolled coil is classified by a label, which includes specifications, order name, destination etc., according to the domestic and foreign orders (here in after referred as labelling). It is necessary for two workers for 24 hours in day and night shifts to perform this process, and the position of the label is not labeled in an exact position because it is hand work. Because the back of a label is applied by strong adhesives, the product of a labeled part will be cut by the user. It is not easy to leave the parts out of account according to the position of a label.

In the consideration of an automation for this process, the reason for difficulties in building an automatic process for this process is that quantitative data for each rolled coil is hard to receive from the previous process and is not possible to apply for a general and simple purpose robot that is actually worked through a taught position to the process because the size and direction of coil differs on every shipping. For this reason, we apply the 6-axis vertical multi-joint robot IRB 3200 and vision system (hereinafter referred as robot vision system) in order to ensure the variable situation of coil and stability and flexibility of the process.

This study precedes many of the similar previous cases for the process because the effective application of robot vision system holds the key to success. The position and direction of rolled coil plays an important factor in the vision process. Price proposes a 2D object recognition system by using the comparison of the pair of feature points in order to compare the similarity between the sample model and the object [1], and Hu introduces an algorithm applied by the moment invariant [2]. The algorithm proposed by Price, however, has a problem in that the recognition does not succeed in accordance with the discordance of feature points in case of the different position of feature points even though the object has the same ones. On the other hand, the algorithm introduced by Hu has a strong point for the consistency of recognition even though the object has rotated or changed its size in the image. Therefore, this study applies to the moment invariant algorithm proposed by Hu to detect the position and direction of rolled coil. In addition, the algorithm of the calibration and robot position error compensation is applied by the analysis of the relationship of transition in a space coordinate system [3]. The similar case for the automation of this process is not built in Korea yet. In case of outside of the country, the Daihen steel mill of NEW JAPAN steel mill co.ltd in Japan has an automatic labelling system equipped with a FANUC robot, laser sensors, automatic label separate type printer, and the others (here in after referred as Daihen system) [4]. The Daihen system, which hold a worldwide technical patent already, is far better than our system in this study. The reason is that the precision of repetitive position of the conveyor and widen of rolled coil, which may imposes a heavy burden on the transition of the existing hand work labeling process to an automatic process, and standardization of the production line has much better conditions than that of the iron mill equipped with our system. Therefore, the construction of this system is designed more intellectual to accept the various difficulties in the aspect of techniques and shows a good point compared with the Daihen system in accordance with the independent operation and simplicity of the system according to the actual application in production line.

Furthermore, this system is still introduced to the production line because of the improvement of the productivity due to the high rate of operation, compact, and stability of the quality of labelling.

II. Construction of an automatic labelling system

A rolled coil shows various types due to the order based products as shown in Fig 1 and presents an irregular pattern for the position and size of the gap between the start position and the end position of coil according to the materials of rolled coil.

The major problems for the transition of the previous hand work labelling process to an automatic labelling system are as follows.

① The mass production of rolled coil is hard to succeed with the present way of automation because a rolled coil has a different size, weight, and thickness due to the order based production.

② The production line has no quantitative data on the size, weight, and thickness of rolled coil because it is built on the assumption that the labelling will be done by hand.

③ A general or simple purpose robot, which can only be operated by the constant and repetitive position, causes a collision because the repetitive position errors of the conveyor that transfers the rolled coil is large enough, and the position and size of the gap between the start position and the end position of coil is irregular.

④ The back of a printed label is applied by strong adhesives and is difficult to treat. In case it is left alone, it will be crushed by the adhesive force.

The robot vision system consists of the elements as shown in Fig 1 in order to accept the mentioned technical problems, ensure the stability of quality, and apply the flexibility of operation.

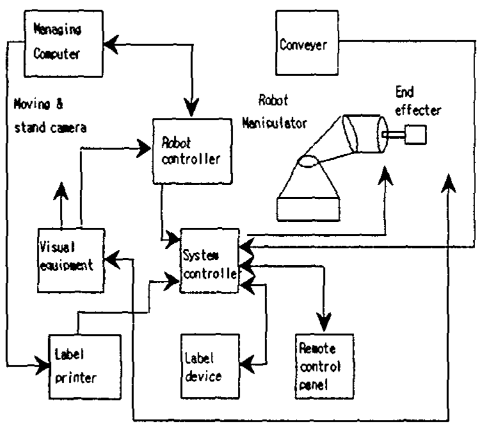

Fig 1. Block diagram of the robot vision system

As shown in Fig 1, the micro-VAX has a role of communication, control, and monitoring for the whole system, and the robot vision system replaces the labors. In addition, the system control and remote panels interlock the secondary devices, the automatic printer has a role to print the information of a label together with the separation of the label from the attached paper, and the label device carries the label.

Therefore, the problem of items ① and ② can be solved by the robot vision system equipped with two CCD cameras as shown in Fig 1. The first CCD camera will be installed as a floor mount type, which induces the pose of robot to the rolled coil by detecting the center position of rolled coil that is varied in its size. The other will be used to detect the start and end position of rolled coil using the rotation of 6-axis after the installation of the CCD camera with an end effector, which is specially designed as a movable type.

The problem of item ③ is solved by the unique function of the IRB 3200 robot, such as searching that it is able to move the proper distance of the attached label using a proximity switch, which is designed as one body of the end effector and camera.

Finally, the problem of item ④ can be handled by the automatic label separating type printer and label device, which is made by some special materials [3].

III. Image processing and robot position error compensation algorithms

The halftoning that is preprocessing for the input image can almost be performed by using the basis of the critical value of histogram. As for a related study, Cheung et al. [5] proposes a multi-critical value setting algorithm that is not changed by brightness to eliminate the changes of brightness with respect to the object as a global scale, and Eschbach et al. [6] develops an algorithm, which stresses the edge by setting the brightness of input pixels.

3.1 Image processing algorithm

In case of applying the algorithm proposed by Cheung et al. to an exposed space, a kind of shield should be required to protect the effects from the changes of brightness. However, it is not possible to install a shield for an iron mill, where the equipment has already been installed by several tens of tons, and makes movement and interference as shown in Fig 2.

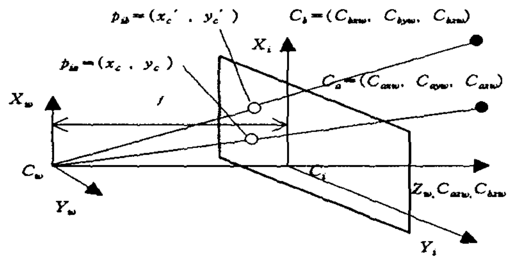

Fig 2. Projective transition model

where,

C_s : Floor mount type camera coordinate system

C_i : Image plane coordinate system

$C_a=(C_{axw}, C_{ayw}, C_{azw})$: Center position of a learned rolled coil

$C_b=(C_{bxw}, C_{byw}, C_{bzw})$: Center position of a different size rolled coil

$p_{ia}=(x_c , y_c)$: Point on the image plane with respect to C_a

$p_{ib}=(x_c' , y_c')$: Point on the image plane with respect to C_b

f : Effective focal length of the camera

Therefore, the algorithm proposed by Cheung et al. is impossible to apply for the process because the exact critical value is hard to define according to the input brightness. Although the algorithm proposed by Eschbach et al. has a drawback on the characteristics of the stress of edge according to the changes of the brightness of surroundings and increased calculations for the process of halftoning, it has a strong point on the simple implementation and high-speed processing. Therefore, this algorithm is to apply as follows. The minimum standard halftoning based on the input brightness $L_s(\min)$ can be applied by Eq.(1), where $I_{\min}$ is the brightness of the darkest pixel in the setting window and I_n (+) is the compensation value.

$$L_s(\min) = I_{\min} + I_n \tag{1}$$

In addition, the maximum standard halftoning $L_s(\max)$ can be applied by Eq. (2), where $I_{\max}$ is the brightness of the brightest pixel in the setting window and I_x (−) is the compensation value.

$$L_s(\max) = I_{\max} + I_x. \tag{2}$$

However, the results of halftoning shows a few changes after applying the Eq. (1) and (2) to the field due to the changes of brightness of surroundings. Therefore, this study minimizes the sudden changes of halftoning using a local light fixed at the end effector with a halogen lamp, which is the same direction of the camera, together with the movable camera.

In addition, a contour is the basic element of recognition of the size and shape for an input image. As for a related study, Prewitt [8] proposes that a contour is to be recognized by the level of gray at the boundary of the different two areas, which have a relatively different level of gray.

The methods for detecting a discontinuity of brightness are as follows.

① A method of surface fitting for the surface function of the changes in brightness.

② A method of an analysis for the second-derivative methods.

③ A method of the changes in colors

④ A method of using the strength of halftoning

However, items ① and ② are very difficult to apply to the field where the brightness of surroundings is frequently changed, even though there are many cases of success in the laboratory. Item ③ is also not applied in the field. Therefore, this study introduces item ④, which makes an easy detection of contour using the critical values given by Eq. (1) and (2). The strength of halftoning $\Delta f(x, y)$ is defined by Eq. (3), where the brightness function for a single pixel of the input image (x, y) is $f(x, y)$, and the operator of the strength of halftoning is Δ.

$$\Delta f(x, y) = \hat{i}\frac{\partial f}{\partial x} + \hat{j}\frac{\partial f}{\partial y}. \tag{3}$$

where,

$\hat{i}$: x-axis direction vector for the brightness

$\hat{j}$: y-axis direction vector for the brightness

Furthermore, the strength of halftoning G_x and G_y for the direction x and y relatively with respect to the eight adjacent pixels is given by Eq. (4), and the value of $|\Delta f(x, y)|$ stand for the value of $\Delta f(x, y)$ is the same as the maximum rate of increase of $f(x, y)$ as presented in Eq. (5).

$$\left.\begin{aligned} G_x &= (x_7+2x_8+x_9)-(x_1+2x_2+x_3) \\ G_y &= (x_3+2x_6+x_9)-(x_1+2x_4+x_7) \end{aligned}\right\} \tag{4}$$

$$|\Delta f(x, y)| = \left[\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2 \right]^{1/2} \tag{5}$$

The direction θ_c is the same as the direction of the maximum increase of brightness function $f(x, y)$ as given by Eq. (6).

$$\theta_c = \tan^{-1}\left(\frac{\partial f}{\partial y} / \frac{\partial f}{\partial x}\right) \tag{6}$$

Therefore, the maximum changes of brightness as a critical point can be detected by using the fact that the more changes in brightness between the adjacent pixels makes the halftoning stronger, and the less changes makes the halftoning weaker. In addition, the contour of rolled coil can be detected by this boundary.

On the other hand, the algorithm proposed by Hu can be used to detect the position and direction of a rolled coil as follows. The $(p + q)$ order moment m_{pq} in a 2D orthogonal coordinate system is given by Riemann integration as shown in Eq. (7).

$$m_{pq} = \iint x^p y^q f(x, y)\, dxdy \tag{7}$$

where,

$p, q = 0, 1, 2...$

$f(x, y)$: the brightness function for a single pixel (x, y)

Therefore, the zero order moment, which means the whole area of the contour, is given by Eq. (8) by using the Eq. (7), where the area of contour is A of a rolled coil, and the circle is l.

$$m_{00} = \iint_A dxdy = \oint_l xdy \quad (8)$$

The first order moments, which have information at the center point of the contour, are given by Eq. (9) and (10).

$$m_{01} = \iint_A ydxdy = \oint_l xydy \quad (9)$$

$$m_{10} = \iint_A xdxdy = -\oint_l xydx \quad (10)$$

In addition, the second order moments, which have information at the principal axis of the contour as the moment of inertia, can be calculated by Eq. (11), (12), and (13).

$$m_{02} = \iint_A y^2dxdy = \oint_l xy^2dy \quad (11)$$

$$m_{20} = \iint_A x^2dxdy = -\oint_l xx^2ydx \quad (12)$$

$$m_{11} = \iint_A xydxdy = \oint_l \frac{1}{2}x^2ydy \quad (13)$$

Hence, the center position of rolled coil can be calculated by Eq. (14) together with the zero and first order moment.

$$x_c = \frac{m_{10}}{m_{00}}, \quad y_c = \frac{m_{01}}{m_{00}} \quad (14)$$

The gradient of x-axis of rolled coil θ_s can be calculated by Eq. (15) together with the second order moment.

$$\tan(2\theta_s) = \frac{2(m_{11} - m_{00}x_cy_c)}{(m_{20} - m_{00}x_c^2) - (m_{02} - m_{00}y_c^2)} \quad (15)$$

3.2 Camera calibration and robot position error compensation

Camera calibration is presented by the position variables that include a unique parameter introduced by some physical data, such as optical characteristics of the lens and the camera system itself, and the position and rotation of the camera coordinate system with respect to a 3D space coordinate system. The value of (x_c, y_c) calculated by the Eq. (14) is the center position of rolled coil in the image coordinate detected by the camera, and then it can be applied to the compensation of robot position error after defining the correspondent relationship between the camera and the rolled coil positioned in the real coordinate system. In order to define the relationship, the point p_{ia} on the image plane of the image coordinate system as shown in Fig 2 can be calculated by the internal parameters of the camera system with respect to the center position of rolled coil C_a learned in the space coordinate system as follows.

$$\left.\begin{aligned} x_c &= \frac{C_{axw}(f - C_{azw})}{f} \\ y_c &= \frac{C_{ayw}(f - C_{azw})}{f} \end{aligned}\right\} \quad (16)$$

Therefore, the actual displacement of rolled coil in the space coordinate system can be obtained by the calculation of changed center position in the image coordinate system using the Eq. (16) even though a rolled coil, which has a center position of C_b or different center position, is introduced. Hence, the relationship between the points p_{ia} and p_{ib} on the image plane can be calculated by Eq. (17) as shown in Fig 2.

$$\left.\begin{aligned} x_c' &= x_c \pm \Delta x_c \\ y_c' &= y_c \pm \Delta y_c \end{aligned}\right\} \quad (17)$$

Here, the value of $(\pm\Delta x_c, \pm\Delta y_c)$ is the variable data of (x_c, y_c) due to the introducing of the different size of rolled coil. The relationship of transition

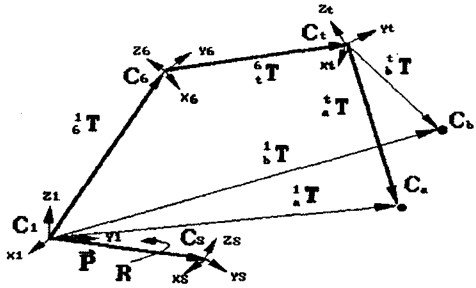

Fig 3. Coordinate system of the robot vision system where,

C_1 : Base coordinate system of the robot

C_6 : 6-axis coordinate system of the robot

C_t : Coordinate system of the robot end effector

C_w : Space coordinate system of the actual rolled coil positioning

${}^{1}_{s}T$: Transition matrix between the robot base and the fixed camera

${}^{1}_{6}T$: Transition matrix between the robot and the 6-axis

${}^{6}_{t}T$: Transition matrix between the 6-axis of the robot and the end effector

${}^{t}_{a}T$: Relative position of the end effector for the position of C_a

${}^{t}_{b}T$: Relative position of the end effector for the position of C_b

$\vec{p}$: Positional transition vector of the camera based on C_1

R : Rotational transition vector of the camera based on C_1

$^{1}_{a}T$: Transition matrix between the robot base and C_a

$^{1}_{b}T$: Transition matrix between the robot base and C_b

As presented in Fig 3, the transition matrix can be given by Eq. (18), if the center position of rolled coil is located at the learned position C_a.

$$^{1}_{a}T = {}^{1}_{6}T \cdot {}^{6}_{t}T \cdot {}^{t}_{a}T \tag{18}$$

The end effector is attached at the 6-axis of the robot, and its coordinate C_t is given by Eq. (19) because the direction is the same as the C_6 of the 6-axis robot coordinate system but has a different position.

$$^{6}_{t}T = \begin{bmatrix} 1 & 0 & 0 & p_{xt} \\ 0 & 1 & 0 & p_{yt} \\ 0 & 0 & 1 & p_{zt} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{19}$$

where the center positions of end effector coordinate system C_t presented by p_{xt}, p_{yt}, and p_{zt} are measured at the C_6 of the 6-axis robot coordinate system.

In addition, $^{1}_{a}T$ is the transition of C_a viewed from the robot base coordinate system C_1 and is given by Eq. (20) because C_a and C_b are defined as a parallel coordinate axis.

$$^{1}_{a}T = \begin{bmatrix} 1 & 0 & 0 & p_{xa} \\ 0 & 1 & 0 & p_{ya} \\ 0 & 0 & 1 & p_{za} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{20}$$

where the values of p_{xa}, p_{ya}, and p_{za} are the original coordinate system of C_a based on C_1.

Furthermore, the position vector $\vec{p}$ and rotational transition matrix R of the camera based on C_1 using the transition matrix of the camera coordinate system $^{1}_{s}T$ presented in Eq. (21) based on the robot base is to be defined in order to find the position variables of the camera.

$$^{1}_{s}T = \begin{bmatrix} R & \vec{p} \\ 0 & 1 \end{bmatrix} \tag{21}$$

If the center position of a newly introduced rolled coil is C_b, the equation of the relative position $^{t}_{b}T$ where the end effector is to approach to the position of C_b can be given as Eq. (22) and (23).

$$^{t}_{b}T = {}^{6}_{t}T^{-1} \cdot {}^{1}_{6}T^{-1} \cdot {}^{1}_{b}T \tag{22}$$

$$^{1}_{b}T = \begin{bmatrix} 1 & 0 & 0 & p_{xb} \\ 0 & 1 & 0 & p_{yb} \\ 0 & 0 & 1 & p_{zb} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{23}$$

where the values of p_{xb}, p_{yb}, and p_{zb} are the *original* coordinate system of C_b based on C_1. Therefore, the transition of the robot with an actual position error compensation is given by Eq. (24).

$$^{1}_{6}T = {}^{1}_{b}T \cdot {}^{6}_{t}T^{-1} \tag{24}$$

where $^{6}_{t}T^{-1}$ can be calculated by the Eq. (19), and $^{1}_{b}T$ can be obtained by the analysis of IRB 3200 kinematics [3] after the substitution of the result of Eq. (23), and then the compensation values of *position for each joint are to be acquired.*

IV. System operation and comparison with the present system

4.1 Results of the system operation

The detection used by the floor mount type camera for the exterior circle and center position of rolled coil is shown in Fig 4, and the results of the start *and end section of rolled coil using the* movable camera is presented in Fig 5.

(a) Actual image (b) After image processing

Fig 4. Image detected by the fixed camera

(a) Actual image (b) After image processing

Fig 5. Image detected by the movable camera

Table 1 presents the data θ_s of the point p_{ia} on the image plane for the center position of rolled coil located at the learned position C_a and the Eq. (15).

Table 1. Results of the center and direction of the coils.

(x_c)	(y_c)	(θ_s)
256.0	157.9	0 : constant

4.2 Comparison with the present system

The automatic considerations for the two iron mills are shown in Table 2 according to the comparison between the Daihen system and our system, and the operation methods and mechanisms of the system are presented in Table 3.

As a result, our system shows better results than that of the Daihen system in spite of the poor automatic considerations as follows.

Table 2. Comparison with the automatic considerations

Item	Our System	Daihen system
Gap of the start section of coil	± 10~ ± 15 mm	within ± 10mm
Gap of the end section of coil	within ± 100mm	within ± 30mm
Rotation gap on the conveyor	± 100~ ± 120mm	within ± 100mm
Precision of the conveyor position	± 5~ ± 35mm	within ± 20mm

Table 3. System operation methods and mechanism

Item	Our system	Daihen system
Label Separation	Using a time belt, mechanical troubles due to the belt	Using an extra unit, good for the wide label
Labelling	Using a suction pad with an end effector, silicon rubber roller	Using a spring and rubber roller with an end effector
Number of M/C	Max 3	Max 2
Cycle Time	Within 215 sec (3 labelling)	Within 180 sec (2 labelling)
Robot Operation	Fixed type	Track motion for the robot movement
Control	Variable programming (Intelligent system)	Variable programming

① The robot of the Daihen system can only be approached by the rolled coil after receiving the information of center position of the rolled coil from the prior computer differed from our system.

② In case of the Daihen system, the start section can be detected by the two laser sensors that measure the distance (X, Y) between the sensors with the range of 80mm. Therefore, it shows an error for detecting at bumpy sections, and the detection is hard for the thin rolled coil below 1.2mm.

③ The Daihen system can only be operated by receiving the data of robot position, distance, etc. from the prior computer. Therefore, it presents a complicated operation and unnecessary actions for each introduction of new rolled coil.

V. Conclusions

This study implements a fully automatic labelling system for a rolled coil that is produced by an iron mill according to the order of a customer for the first time in Korea.

As a result, the 12 labors rearranged the other highly effective places among 48 total labors with respect to the production field of four automatic lines with 3 shifts in the view of compactness. In addition, the rest of the 32 labors survey the number of troubles and time for 3,200 hours in day and night that shows a stable and reliable system up to the success rate of 99.7%.

References

[1] K. E. Price., "Matching Closed Contours," *Proc. 7th Int. Conf. on Pattern Recognition*, pp. 990-992, July-Aug. 1984.

[2] Hu, M. K., "Vision Pattern Recognition by Moments Invariant," *IRE Transactions on Information Theory*, vol. 8, 2. pp. 179-187, 1962.

[3] TAMAKAWA Precision machinery co. ltd, "*Feature of Auto labeling System Using General Purpose Robot*," Monthly Publication Automatic Technology, vol. 24, no. 11, pp. 73- 77, 1992.

[4] Cold & Hot Rolling Coil, Specification for Label Attaching Robot, TAMAKAWA Precision machinery co. ltd, 1992.

[5] W. P. Cheung, C. K. Lee, and K. C. Liaccv, "Brightness Invariant Multi-Threshold for Grey Level Template Matching," *'93 Asian Conference on Computer Vision*, Nov. 23-25, OSAKA, JAPAN.

[6] Eschbach, R. and Knox, K., "Error-Diffusion Algorithm with Edge Enhancement," *journal of the optical society of America*, vol. 8, no. 12, pp. 1844-1850, Dec. 1991.

[7] Prewitt, J. M. S., *Object Enhancement and Extraction*, pp. 75-150. Academic Press, New york.